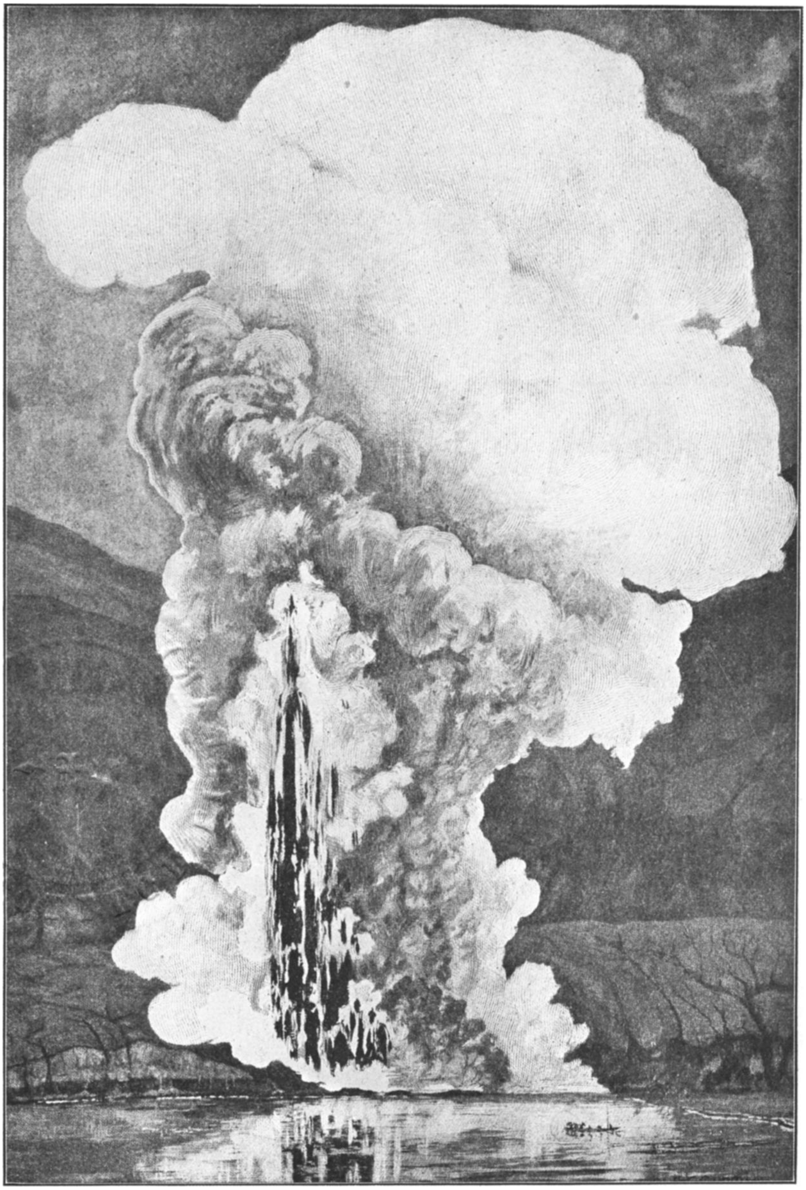
SECONDARY PHENOMENA OF THE WEST INDIAN VOLCANIC ERUPTIONS OF 1902.[1]

A COMPLETE report on the secondary volcanic phenomena of the West Indian eruptions of 1902 should include at least the following topics:

Development of consequent streams upon an initial ash surface.
Stream deflections by volcanic ejecta.
Subsidence of coastal plain.
Elevation of marginal deposits.
Effect of "tidal" or reflex waves.
Results of marine erosion.
Sedimentation of sea deposits.
Eruption within stream valleys.

The latter subject has been selected for this paper, leaving the others for later publication. According to some views I should include also as secondary phenomena the earthy flows of detrital matter which have played an important part in the destruction both of life and property, and have been generally reported as "mud flows." I regard them as, in part at least, of primary volcanic origin and think that the "mud flow" which buried the Guerin sugar works on May 5—two days before the destruction of St. Pierre—was a result of an eruption from the crater of Mount Pelée. After the great eruption of May 7 on St. Vincent, more than half a billion gallons of water had disappeared from the crater lake of La Soufrière, which we found, on reaching the crater's rim on May 31, to have fallen about 800 feet below its former level. The evidence indicates that this volume of water was poured out over the mountain, bearing with it bowlders and "earth." This "earth" was composed of soil washed from slopes, the finer fragments of volcanic ejecta, and comminuted rock which has been commonly referred to as "ash." Mingled with widely varying percentages of water, the mixture was generally termed "mud," and in many instances "lava." In the May 6

[1] Paper read before the American Association for the Advancement of Science, January 2, 1902.



By permission of the "Century Co."

FIG. 1.—Outburst of dust-laden steam at the mouth of the Wallibou river, St. Vincent.

issue of *Les Colonies* (the last save one of this St. Pierre journal), under the headings "La catastrophe de l'Usine Guérin," the "flow" is described as "le débordement de lave." About noon on May 6 — the day before the memorable eruption — the inhabitants of St. Vincent, on both leeward and windward sides of the volcanic cone, saw the paths of the principal rivers flooded with "mountains of steaming waters." On June 24 I saw from its banks the catastrophic rush of earth, and bowlders, and water which plowed through the channel of the Sèche river. This flow took place during one of the heaviest of the minor eruptions of Mount Pelée, which, however, had been preceded by four

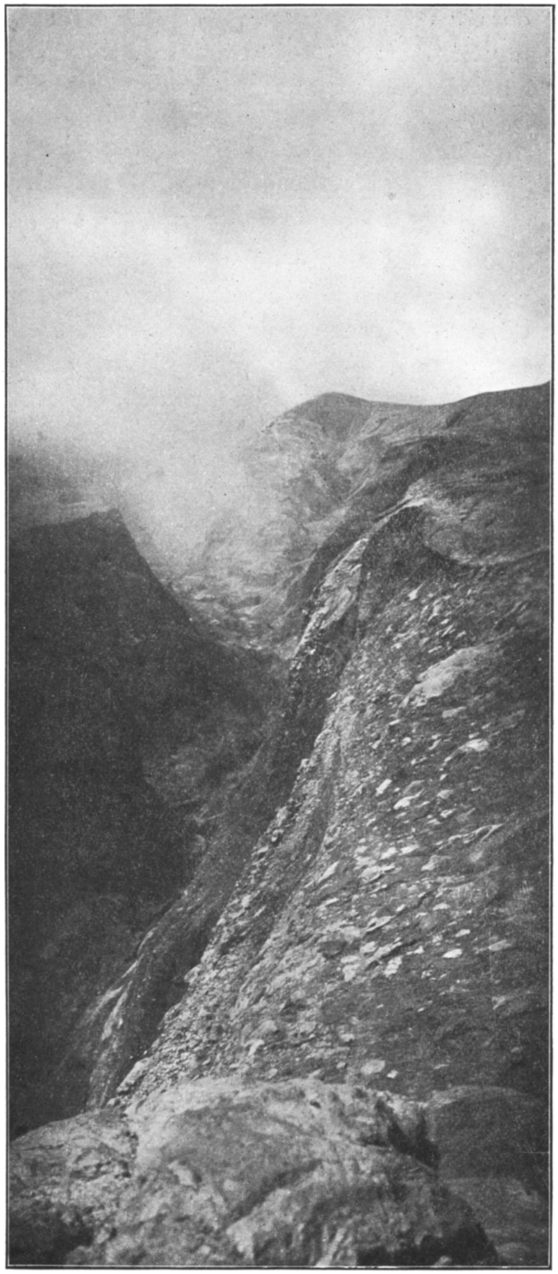


FIG. 2.— The Terre Fendue; or outlet to Pelée crater (eruption cloud obscures inner fragmental cone). Taken from the highest spurr of the "St. Pierre" ridge, which trends across the head of the Blanche river, by C. C. Curtis on June 26, 1902.

hours of very heavy rain. Two days later I reached the spur of the "St. Pierre ridge" which trends across the "Terre Fendue," or lip of Pelée's crater. It was possible from this position to see directly into the crater. During a minor outbreak, the channel of the gorge began to send out vapor, while its water both visibly and audibly increased. This I interpreted as erupted water. On May 8, according to M. Déseré, mayor's deputy at Grande Rivière, at 4 A. M.—four hours before the destruction of St. Pierre—a great flood, bearing bowlders up to six feet or more in diameter, came rushing down and buried the lower part of the town some twelve feet, where the stream formerly debouched into the sea. There had been little rain before this flood. Similar floods took place at this village of Grande Rivière on May 11, on June 6—the day of perhaps the heaviest eruption of Pelée on record—and on June 22 (when I was about two miles off the delta of the Grande Rivière, in a sloop, though unaware of such occurrence). Little rain fell on this day. The towns to the southward, situated at the mouths of streams heading on Mount Pelée, were visited by similar catastrophes.

From these accounts it appears that the major eruptions have been accompanied or preceded by "mud flows," and evidence indicates that the waters of the crater lakes have been discharged over the mountain sides. If fragmental material has accompanied these ejections of water, as it has the other eruptions, it is reasonable to assume that much of it would have been carried down into the lower valleys. The fine dust which was observed to be accumulating within the crater of Pelée would be swept down during such a flood, together with much of the fragmental material lying upon the inner cone. Re-ejected material, both coarse and fine, which had fallen within the crater might be either washed down the inner cone and out through the lip, or in a stronger outburst deluged over the upper slopes of the outer cone to be distributed by the summit-heading valleys. Dr. E. O. Hovey has reported these "mud flows" as due to landslides.[1] While this may account possibly for some of the minor occurrences, it can explain with difficulty the great volume of water necessary to convert the

[1] *Bull. Am. Mus. Nat. Hist.*, Vol. XVI.

unconsolidated cover over the bed-rock into a liquid-like torrent moving with great rapidity, and maintaining this state for several miles from its assumed source, especially since the remarkably porous quality of the "ash" cover renders it a very poor water-bearing medium. Some of the small, viscous-flowing mud streams originated in the cutting down of landslide dams behind which stream water had accumulated, as we observed on St. Vincent, but it is difficult to conceive how in the narrow, steep, graded canyons, large bodies of water could be collected sufficient to have caused the greater flows. Drs. Anderson and Flett[1] state that the "crater lake of La Soufrière was probably driven down over the lip of the crater and poured

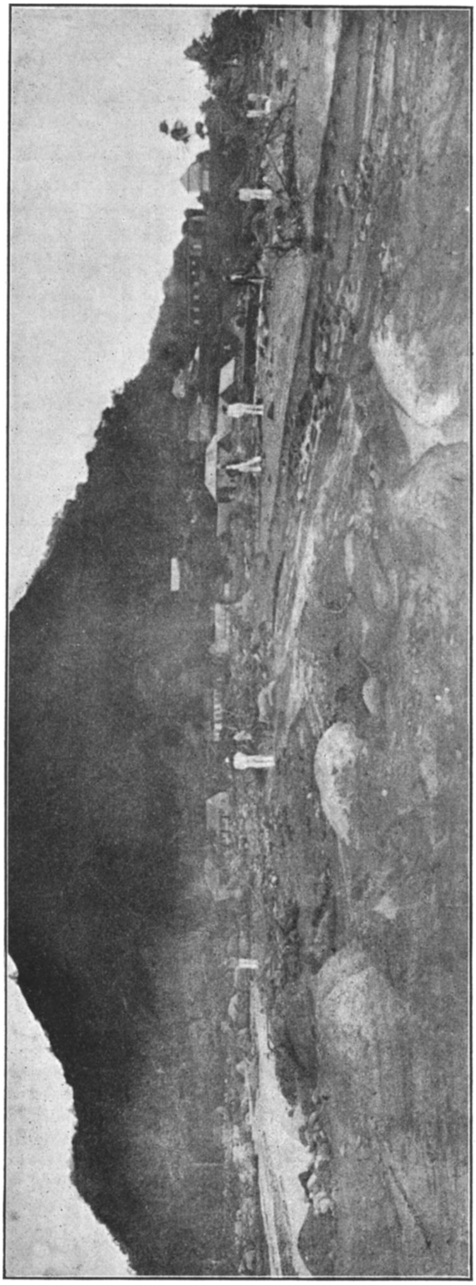


Fig. 3.—Delta of the Grande Rivière. Showing character of flood deposit which destroyed lower portion of the town. Natives standing along former shore line.

[1] *Proc. Royal Soc.*, Vol. XX, p. 426.

down the valleys into the sea." The transporting power of such a flood is tremendous. Professor Angelo Heilprin says of the flood of May 5:[1]

"Hardly had the mid-day hour passed when the gates of the volcano were drawn, and a flood of boiling mud was sent hurling down the mountain side to be flung from it into the sea. In three minutes it had covered its three miles to the ocean. . . . . It is needless to ask whence came the mud; it could plainly be traced to the position of the Soufrière or Étang Sec."

Dr. T. A. Jaggar writes:[2]

This crater [Pelée] ends in a deep gulch west that extends down to the sea. . . . . Apparently it was down this gulch that the mud flood came which overwhelmed the Guérin factory.

M. Parel, Vicar General of Martinique, in his memorable record of the beginning of the disturbances on Mount Pelée,[3] states:

Since the morning [May 5] Rivière Blanche, which for some days had been swelling to disquieting proportions, although there had been no rain, had assumed suddenly the aspect of a menacing and muddy torrent. . . . . At the same time a moving column of vapor was seen in the high valley (see Fig. 2) that extends from the crater. . . . . It was an avalanche of black mud, ejected by the crater, and swollen by successive discharges until it became a rolling mountain, while it was breaking its way through the deep gorge. The moment it approached the delta, its presence was betrayed by the ascending vapors.

This show of vapors indicates the presence of some steam-generating factor, which was probably heated bowlders thrown out of the crater with or previous to the erupted flood, and borne down with it.

These observations indicate that the "mud flows" must be included with the primary volcanic phenomena of eruption as well as with the secondary.

VALLEY ERUPTIONS.

Perhaps no phenomena observed in the recent West Indian eruptions have led to more misinterpretation than the eruptions which were observed within the confines of valleys and canyons.

[1] *Mt. Pelée and the Tragedy of Martinique*, J. B. Lippincott Co.

[2] *Popular Science Monthly*, August, 1902, p. 359.

[3] *Century Magazine*, August, 1902.

Persisting after the great eruptions from the summit craters, they formed a source of intermittent anxiety to the inhabitants left near the borders of devastation, and one of considerable misinterpretation by the early explorers, who saw the voluminous outbursts only at a distance.

From afar these eruptions appeared as occasional outbursts of steam, whose snow-white bulging tops were sometimes mingled with tints of brown or shaded with deeper grayish color; "black mud" was reported to have issued from them; hence the name of "mud craters" was applied by some to the sites of these outbursts. Professor Angelo Heilprin, in his article, "Mount Pelée in its Might,"[1] speaks of "vents of the Falisse river acting as safety valves for Pelée." Professor Heilprin, in an account of his second visit to Martinique,[2] says:

> When my observations were made, I was not near enough to clearly ascertain its features, and relied for my determination largely on the observations of others. A closer examination of the gorge leads me to very strongly doubt the crateral origin of the outbursts—a doubt which has already been expressed by Lacroix and others.

Mr. Robert T. Hill, in his report on the volcanic disturbances in the West Indies[3] has prepared a map on which he locates three "mud craters," each over a mile from the crater of Pelée, and has located a "Soufrière crater" on the Rivière Blanche half way between the summit and the sea.

Of the hundreds of these eruptions from "lower craters" which I saw during the forty-eight days on these islands, one which occurred at the mouth of the Wallibou river, St. Vincent, on May 30, and another in the Sèche river on June 24, both witnessed at close range, may serve as the basis of a description of these phenomena.

While passing the Wallibou river in a dug-out canoe on the afternoon of May 30, a great cloud of vapor suddenly sprang from the stream, accompanied by a cannon-like roar. The column of steam rose to a height estimated at over 3,000 feet, and passed from a straight geyser-like jet into a bulging top ten

[1] *McClure's*, August, 1902.

[2] *Op. cit.*, p. 214.

[3] *National Geographical Magazine*, July, 1902.

times its base in width. Now and then black finger-like masses shot up into the curling vapor, were sustained for a minute or more, and then sank back out of view. At other times the jet appeared a solid column of black, during which the steam cloud would change from white to golden tints, and, as the violence increased, to grays. The black jets were composed

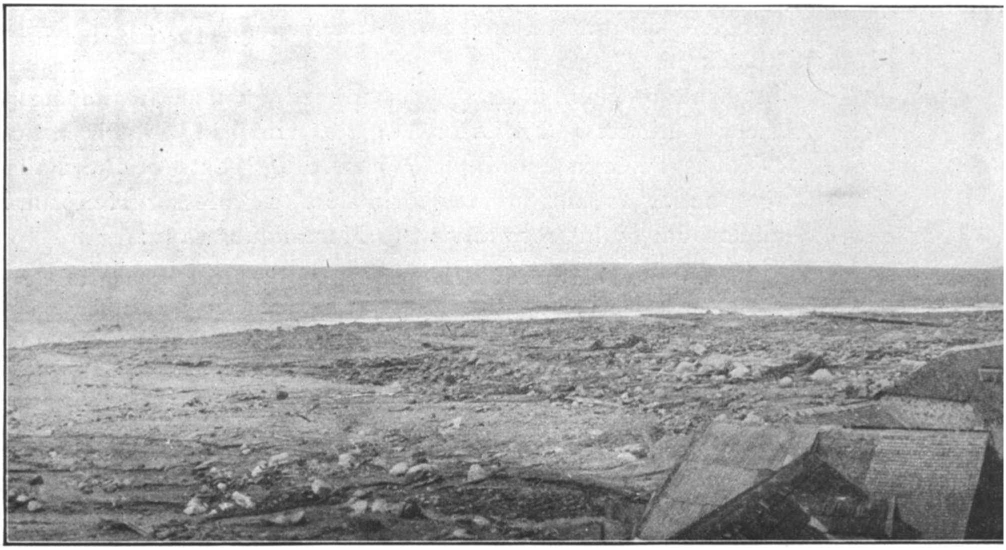
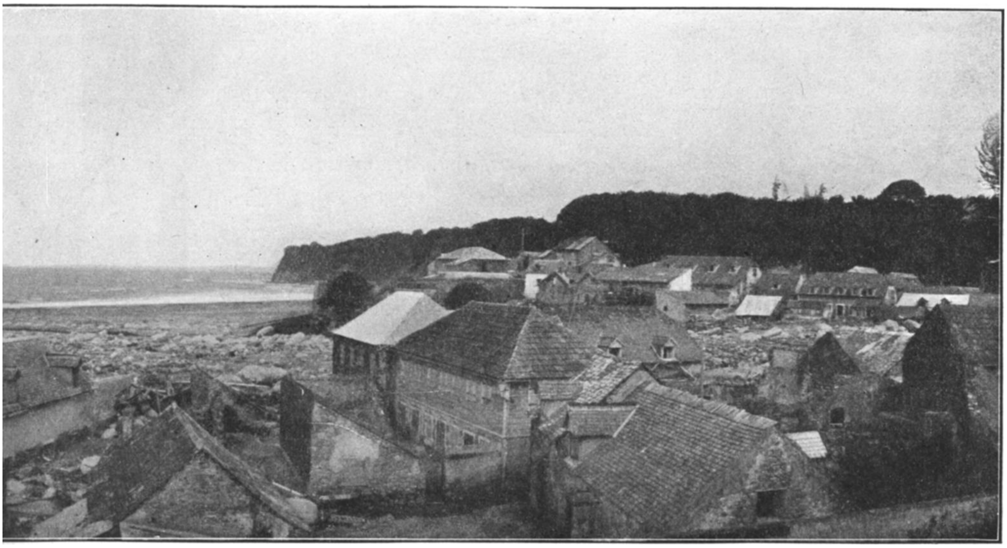


FIG. 4.— Delta at Basse Point. Showing encroachment of mud flows upor

of erupted sand and rock fragments from the stream bed, and the changing color of the steam cloud indicated that some of the finer particles were carried even to its balloon-shaped top. Indeed, this erupted ash soon began to fall upon us until boat and crew alike were completely covered with a snow-like fall of gritty, gray dust. The eruption cloud itself quite simulated those from the crater of Pelée; the straight, black, rigid column at the base, the writhing, twisting puffs of brain-like formed globules with brownish hue above, and the lighter-colored, spreading pine-tree cloud on top which floated off with the trade wind in distinct globes, each indicating a different time of outburst.

It is scarcely a cause for wonder then, that these minor manifestations, with their spectacular appearance, were early regarded as originating from lateral craters connected with the main vents. From the location of these outbursts in stream beds it came to be reported that St. Pierre had probably been destroyed by a lateral crater in the bed of the Blanche river.[9]



: the sea. Half buried houses in foreground are close to the old shore line.

The particular eruption witnessed in the Wallibou took place about an hour after the beginning of a very heavy tropical rain which sent sand-filled water in sheets down over the sea cliffs and changing valleys. The river, which had maintained a mere showing of water, became a steaming torrent several feet in depth, instigating the explosion.

I was within the valley of the Sèche in the mud flow of June 24, when returning from an ascent to the crater of Pelée from the St. Pierre side, and saw in the bed of the avalanche-swept stream below, which we had just crossed in ankle-deep

[9] A. HEILPRIN, *McClure's*, August, 1902; R. T. HILL, *Century Magazine*, September, 1902, GEORGE KENNON, *Outlook*, Vol. LXXI.

waters, an eruption which threw its column of steam to a height of over half a mile. I found opportunity to visit the sites of both these explosions on the days following, and to examine them closely. From these and numerous other observations, especially in the Rozeau Dry river of St. Vincent, where the phenomena were best developed, it appears that the geyser-like eruptions may be explained as secondary phenomena.

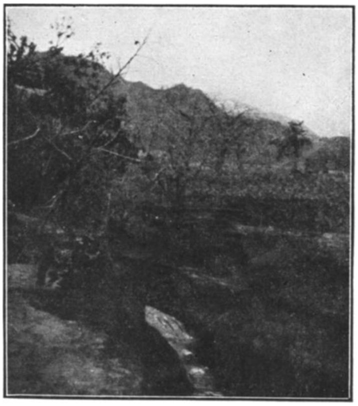


FIG. 5.—Small, viscous mud stream—5 feet wide—flowing by pulsations in canyon north of Precheau.

Mechanics of "ash-geyser eruptions."—The beds of nearly all, if not all, of the rivers which head at the summit craters of La Soufrière and Mount Pelée contain deposits of volcanic ejecta generally known as "ash" in depths from a few inches to one hundred feet or more. This fragmental material ranges from the size of a block 22 by 50 by 24 feet in the Sèche river to impalpable dust. In some instances where the surface is more thickly strewn with bowlders, these rocks have been found to be hot enough to cause cracking of their surfaces, even fumerole-like deposits forming about them. In other places where the stream has deeply intrenched these deposits of volcanic ejecta, it has opened a passage between beds which are hot enough to burn the shoes, and clouds of mingled unconfined steam are given out whenever the hot dust slips into the stream water or the sea.

The mouths of the Blanche, the Sèche, and the Wallibou presented the best examples of these dissected hot-ash beds. When the bed of the stream was dry—its prevailing condition—little indication of this underlying high temperature within the deep stream deposits was apparent, save in the rare instances of hot bowlder surfaces and the mild steaming of the beds from small pits, through which hot vapor was sometimes rising, with the distinct blowing noise of escaping steam. These vents were

evidently outlets of underlying heated deposits, which, whenever reached by sufficient water, expressed themselves by the geyser-like eruptions.

Process of eruption.—Over the bed-rock bottoms of the peripheral streams a certain considerable amount of flood-plain deposit

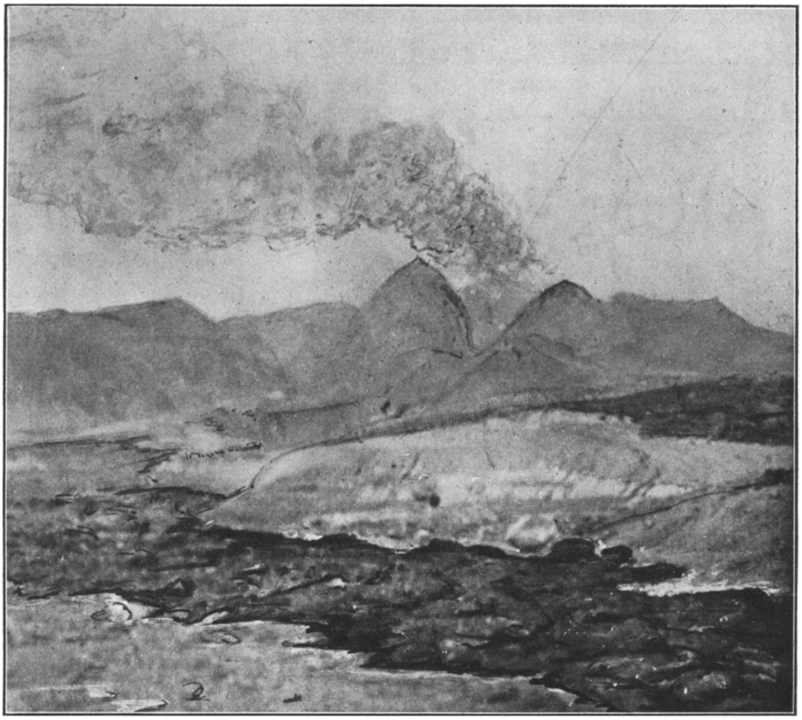


FIG. 6.— Mud flows on Blanche Lake divide.

had taken place before the eruptions. Upon this plain, and well up upon the including valley walls, were deposited hot volcanic ejecta of dust and bowlders. The high temperatures of the latter were maintained, aided by the blanket covering of overlying ash; and by their gravity they had tended to gather in the old river channel, forming loci of concentrated temperatures. Into these heated beds water percolated from above. The vapor generated by contact with the hot rocks increased until it sud-

denly found vent by eruption through the impounding beds; thus a chimney or vent was formed through which copious supplies of water were poured during the intervals of explosion, to be ejected again from the same pipe.

The instigation of eruption.—On reaching the hot, covered ash beds in sufficient quantities, the water must bring about geyser-like explosions until the underground heat is dissipated. There

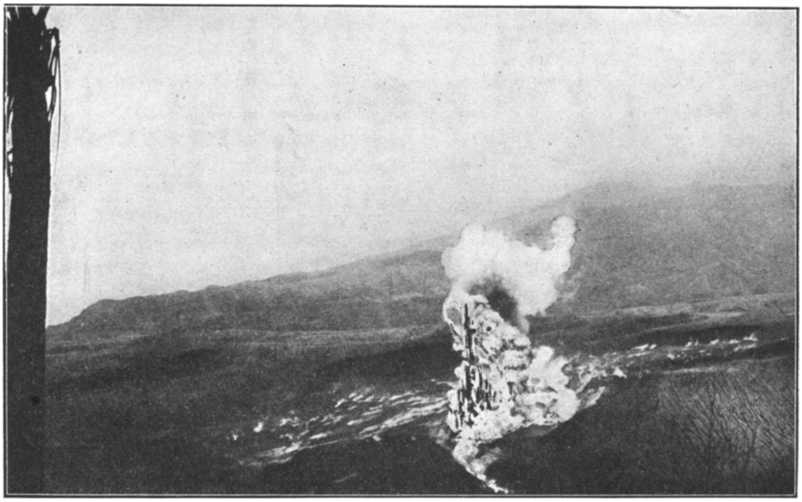


FIG. 7.—An ash geyser eruption in the bed of the Wallibou river. Soufrière crater in the distance.

are a number of distinct processes by which this water manages to collect in sufficient quantities to instigate eruption. One is the flooding of the stream channel by a sudden tropical downpour, as observed on May 30; another is that of an eruption flood from the primary crater—as that from Mount Pelée on June 24. Still a third process, one of gradual accumulation, is that which obtains its water supply by the damming of the stream through landslides. I observed this in the Wallibou river at 8 o'clock on the morning of May 30. A portion of the undercut riparian ash banks had fallen, slipping across the channel, and by thus damming the stream caused a lake to form behind this barrier. When its water had reached and covered a certain place near

the right bank of the stream, an explosion suddenly took place, continuing with the usual attendant phenomena of "ash-geyser" eruptions. The explosion dug the bank rapidly away, adding the erupted detritus to the dam, which by rising increased the supply of water and the force of the explosions. Eventually the lake overflowed and a channel was cut back which, draining

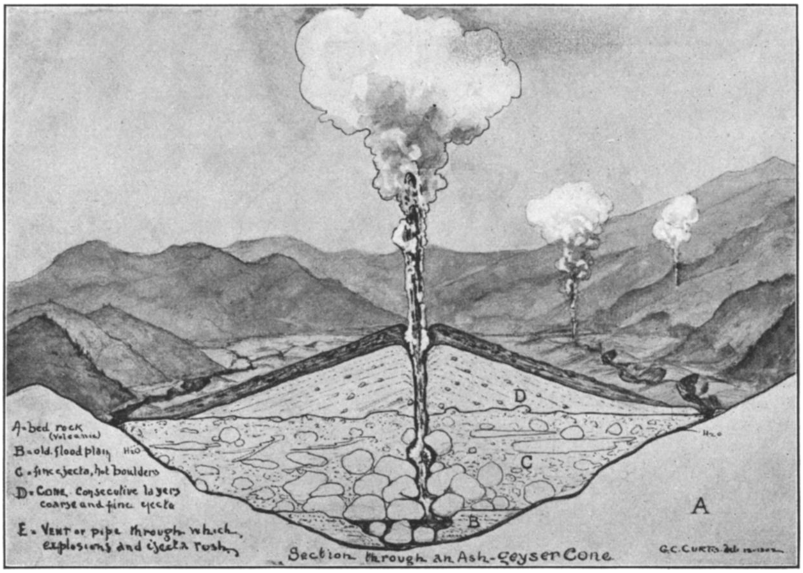


FIG. 8.

it by this outlet, brought a cessation of the eruption. The water may reach the hot-ash bed by filtration through the overlying deposit, or by pouring down the pipe or chimney when the orifice lies submerged.

Description of secondary cones.—The effects of these eruptions within the river courses simulate those of true volcanic craters. Steam rushes up through the overlying beds, carrying with it fragments from below and from the surrounding walls. It throws ejecta, composed of fine and coarse fragments (some were the size of a man's head), to a considerable height (that of a mile being observed), the finer material being doubtless scattered to distances of miles, but the coarse falling within the immediate vicinity of the vent. By gradual accumulation

this collection of sand and coarser fragments grows into a pile about the pipe, tending to assume the form of a perfect volcanic fragmental cone with crater falling into the descending pipe, and slopes averaging 25° to 30° (several cones 40 feet in

FIG. 9.—A secondary (or ash geyser) crater in the Rabaka river trenched by stream.

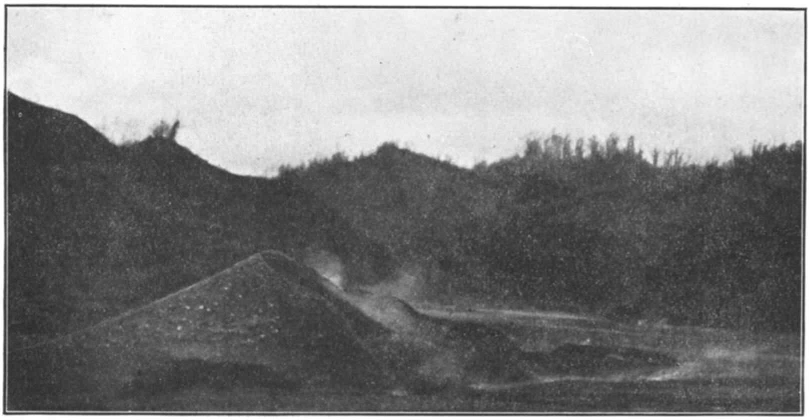


FIG. 10.—A secondary cone—ash geyser cone—partially demolished—Rabaka river. St. Vincent.

height and 160 feet in diameter were observed on both Martinique and St. Vincent).

The accompanying diagram (Fig. 8) represents the structure of the ash-geyser cone.

The ash-geyser, indeed, simulates a miniature volcano both

in topographic form and phenomena of eruption. Professor Russell asks:[1] "What is the crucial test by which a true crater may be distinguished from a pseudo-crater?" as he terms these secondary craters. Five characteristics were noted: first, location—the ash-geyser crater occurs persistently within the streams or the deltas; second, composition—the walls are con-

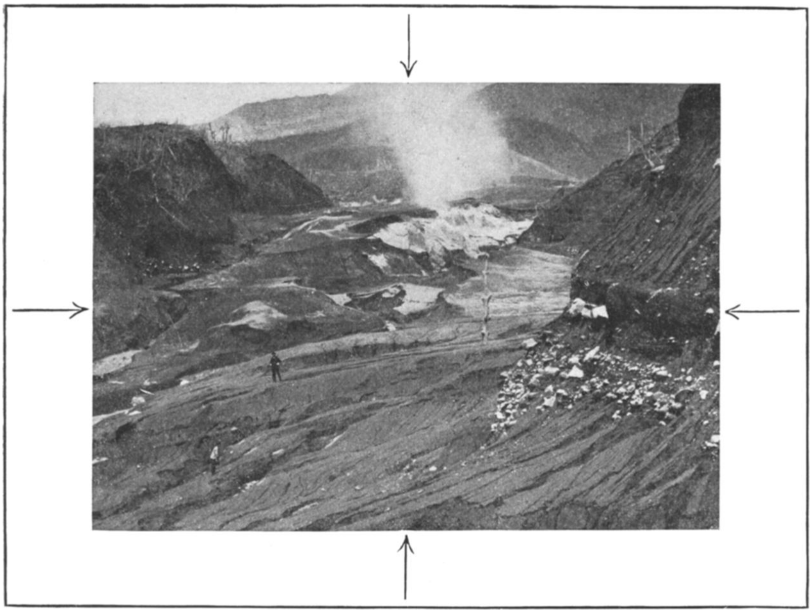


FIG. 11.—Ash cone topography and dissected ash cone lying in the present stream channel—Wallibou river. (Arrows point to cone).

structed entirely of fragmental material and not of old bedrock (the structural layers of the volcanic cone as observed on the rims of the primary craters); third, method of eruption—eruption occurs only in time of water accumulation; fourth, temperature—a relatively low temperature of ejecta; fifth, size—the ash-geyser cone is a small fraction of any true lateral crater observed. I am inclined to account for both the island discovered off the river Blanche on May 23,[2] and which had disappeared on return

[1] *National Geographical Magazine*, Vol XIII, No. 12, p. 416.

[2] R. T. HILL, *Century Magazine*, September, 1902.

to Martinique on June 14, and for the elongated hill of hot bowlders between the 600 and 700 foot level in the Sèche valley,[1] by secondary eruption.

Comparison of ash-geyser cones with other secondary volcanic cones.—These cones, occurring as they do within the valleys and upon

FIG. 12.—Secondary ash cone topography. Rabaka river. Vents slightly "steaming" with mere trickle of water in stream bed.

the "mud lavas," may be compared with those irregular heaps of volcanic scoriae which abound on the tops of some true lava streams, being piled up around each vent or "bocca" which the steam-jets escaping from the lava currents, form at their surfaces. The Vesuvian lavas of 1855 and of 1872 developed such cones on their surfaces.[2]

Ash-cone topography.—I was at first unable to account for the peculiar irregular topography in the channels of the streams soon after the great eruptions. It had the irregular rounded hillock appearance which resembled sand-dune forms. The sug-

[1] HOVEY, *Bull. American Museum*, Vol. XVI, p. 360.

[2] JUDD, *Volcanoes*, p. 101, drawing by Schmidt.

gestion was early offered that a rotary motion of tornadoes which emanated from the summit might account for the mounded topography. I am now persuaded that the rolling character of the stream deposits which doubtless originally had regular flood-plain cross-sections was largely due to this geyser action and to the presence of remnants of these secondary cones. These were left in every stage of demolition by shifting in the vents, by migration of the stream channels, by the degradation of the channel which carried the water surface out of reach of the main vent, or simply by the disappearance of the stream water.

GEO. CARROLL CURTIS.